

# LEAG TOP-SAT: Summary of Results and Science Objectives

G. Jeffrey Taylor

University of Hawai`i

Stephen Mackwell

Lunar and Planetary Institute

# Lunar Exploration Analysis Group

- Community based, **interdisciplinary** forum
- Analyzes scientific, engineering, technology, and operational issues associated with lunar exploration to support the Vision for Space Exploration
- Not limited to science — covers exploration activities, science, resource utilization, and commerce
- Reports findings and analysis to Exploration Systems Mission Directorate and Science Mission Directorate, through NASA Advisory Council

# LEAG Executive Committee

- Chair: Clive Neal
- Vice-Chair: Chip Shearer
- Previous Chair: Jeff Taylor
- Executive Sec and ESMD: Mike Wargo
- SMD: Tom Morgan
- SOMD: Michelle Gates
- Community Liason: Steve Mackwell
- ISRU subgroup chair: Jerry Sanders
- Commerce subgroup chair: Paul Eckert

# LEAG Activities

- All reports online at [www.lpi.usra.edu/leag/reports.html](http://www.lpi.usra.edu/leag/reports.html)
- Also see white paper for this meeting
- Workshop on Lunar Knowledge Requirements for Human Exploration, March, 2004
  - Examined state of knowledge of lunar basic and applied science
  - ORDT for LRO
- First formal meeting, January, 2005
  - Examined issues surrounding human missions
  - Studied robotic measurements and experiments; set rough priorities
  - Developed list of technology demonstrations

## LEAG Activities (continued)

- Specific Action Team: Nature of Second Lunar mission, March, 2005
- Specific Action Team: Science Activities and Site Selection, June-July, 2005
- Co-sponsored “Space Resources Roundtable VII: LEAG Conference on Lunar Exploration”, October, 2005
- Specific Action Team: Review of Plans Developed by the RLEP 2 Measurement Team, March, 2006

## LEAG Activities (continued)

- LEAG TOP-SAT: Review of Themes and Objectives Phasing Document for Lunar Exploration Strategy, July, 2006
- LEAG HAB-SAT: Assessed the relative importance and time phasing of objectives in relation to the theme of Human Habitation of the Moon, Oct. 12-13, 2006
- LEAG GEO-SAT: Assessed relative importance of lunar geoscience objectives in relation to the Science theme

# Lunar Exploration Strategy *Objectives*

**Basic Science** (Astronomy and Astrophysics; Heliophysics; Earth Observation; Lunar Geology; Environmental Characterization)

**Applied Science** (Lunar Resource ISRU; Materials Science)

**Human Health and Biology** (Human Health; Life Support and Habitation; Operations Environment Monitoring; Environmental Hazard Mitigation)

**Infrastructure** (Power; Communication; Guidance, Navigation and Control; Surface Mobility; Transportation; General Infrastructure; Crew Activity Support; Operations Test & Verification)

**Commerce** (Development of Lunar Commerce; Commercial Opportunities)

**Other** (Historic Preservation; Global Partnerships; Public Engagement; Program Execution)

# LEAG Themes and Objectives Phasing SAT

- Review themes and objectives developed by synthesis of products of Exploration Strategy Workshop, Request for Information, and other sources
  - Is the list complete?
  - Are there redundancies?
  - Are the objectives state clearly?
  - Are any themes or objectives overstated or unachievable?

# LEAG HAB-SAT

- Purpose: To assess the relative importance and time phasing of objectives in relation to the theme of Human Habitation of the Moon. This involved:
  - ranking the objectives relative to each other in connection to the human habitation theme
  - identifying the essential capabilities and requirements needed to satisfy each objective
  - identifying which objectives are best done or need to be done on robotic missions
  - identifying which objectives ought to be done on human sortie missions
  - identifying the order in which objectives should be done at a permanent outpost site in order to sustain presence and advance exploration goals

# LEAG GEO-SAT

- Get full report at:  
<http://www.lpi.usra.edu/leag/reports.html>
- Ranked all lunar geology-geophysics objectives as starting point for this workshop
- Did not rank objectives in other science areas because they were being worked by other NAC science subcommittees
- Emphasis here will be on the extent to which the objectives can be met from a single site on the Moon

## LEAG GEO-SAT

Rankings:

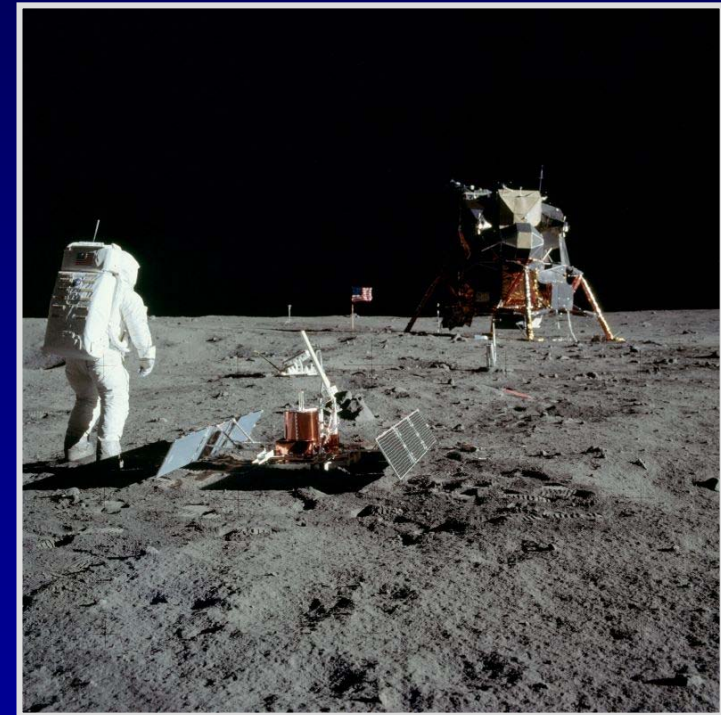
High (8–10): first-order science problem

Medium (4–7): Useful for addressing scientific problems

Low (1–3): Not useful or only marginally useful to addressing scientific problems.

## ***Understand the origin and structure of the Moon --Seismology to probe the interior***

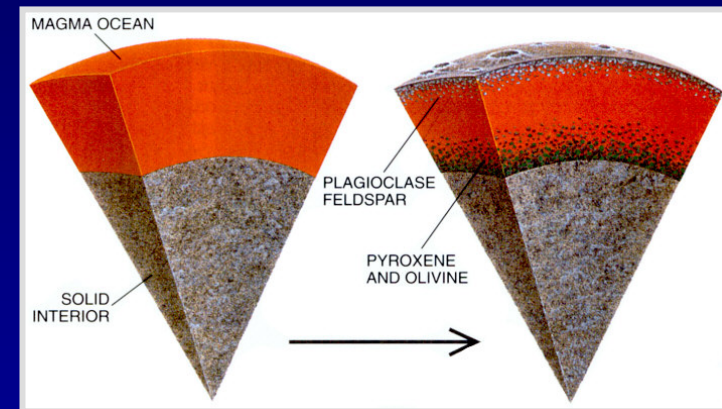
- Ranking: 10
- Single site:
  - Cannot be addressed from a single site
  - A seismic station at an outpost site would represent a start towards establishing a long-duration global seismic network
  - Raises issue of role of robotic missions in architecture



Deploying a seismic station

# ***Understand the origin and structure of the Moon -- Determine the structure and evolution of the lunar crust and mantle***

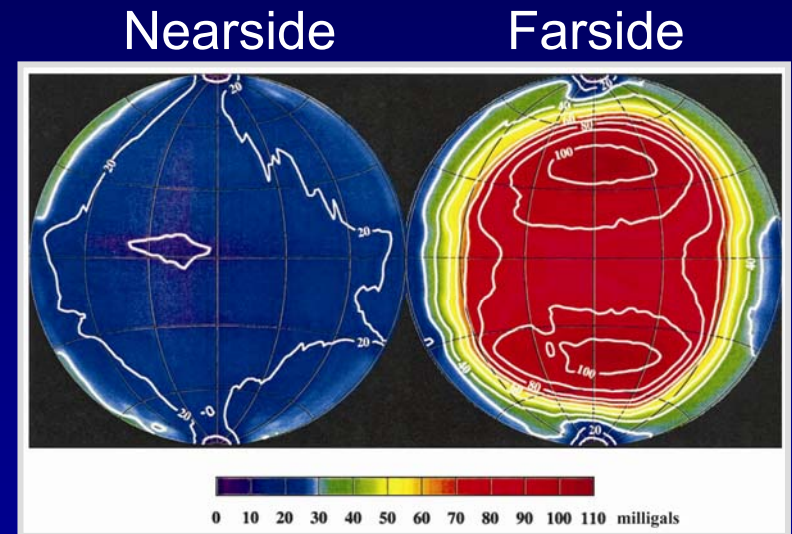
- Ranking: 10
- Single site:
  - Significant progress can be made by intensive study of one site by studying rocks in the regolith
  - How much progress depends on the geological setting of the specific site chosen
  - Proximity to a diversity of geologic terrains is particularly important



Lunar Magma Ocean

## ***Understand the origin and structure of the Moon -- Global geophysical properties***

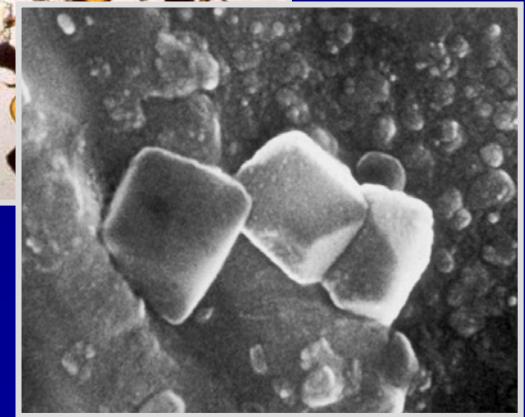
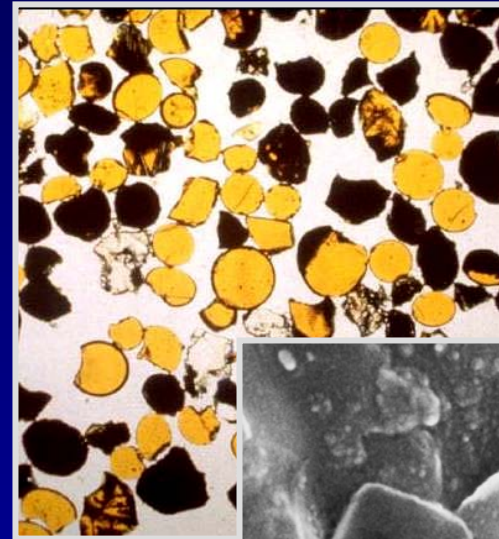
- Ranking: 8
- Single site:
  - Little progress can be made on this objective from a single site
  - Slight exception: a heat flow measurement.



Uncertainty in Lunar Gravity  
(Konopliv et al., 2001)

# *Understand the origin and structure of the Moon -- Endogeneous volatile elements*

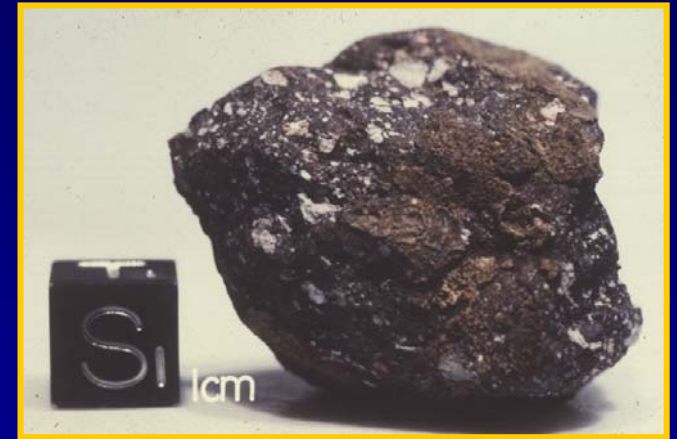
- Ranking: 7
- Single site:
  - If the outpost site were chosen with this objective in mind, significant progress could be made.



Pyroclastic Deposits

## ***Study meteorite impactors on the Moon -- Search for samples of the ancient Earth***

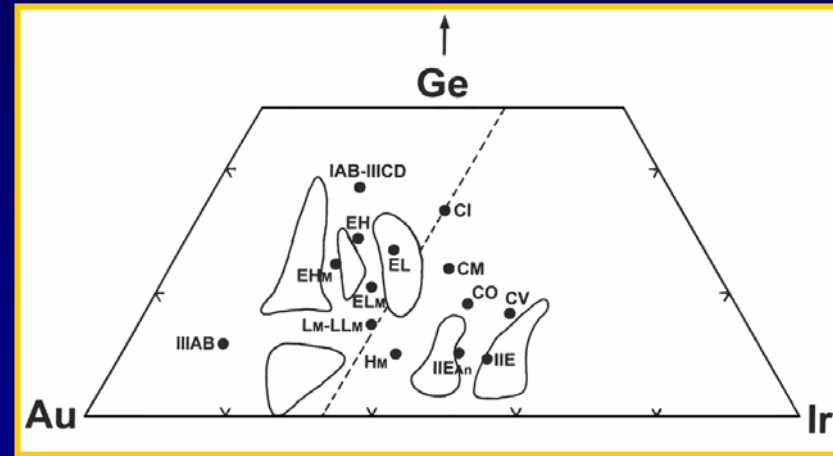
- Ranking: 6
- Single site:
  - A permanently inhabited site making use of in situ resources would enable this objective.
  - Requires automated techniques to search the mined materials for key indicators (e.g., quartz, alkali feldspar)



Meteorite from the Moon

# Study meteorite impactors on the Moon -- Composition of basin-forming impactors

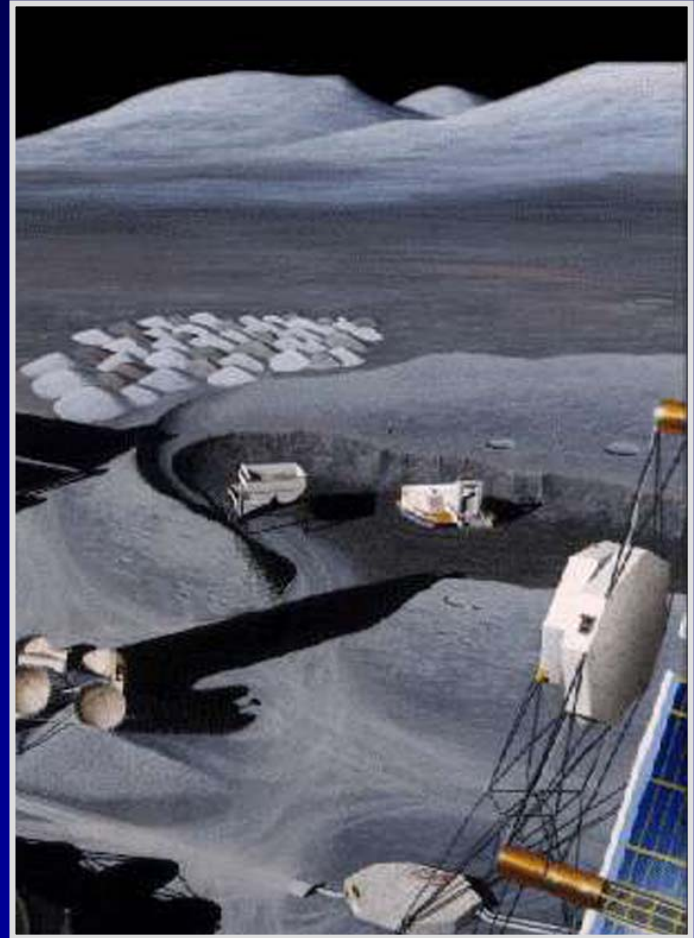
- Ranking: 7
- Single site:
  - Depending on the location of the outpost site, modest progress could be made on the objective.



Siderophile element concentrations  
(Kring and Cohen, 2002)

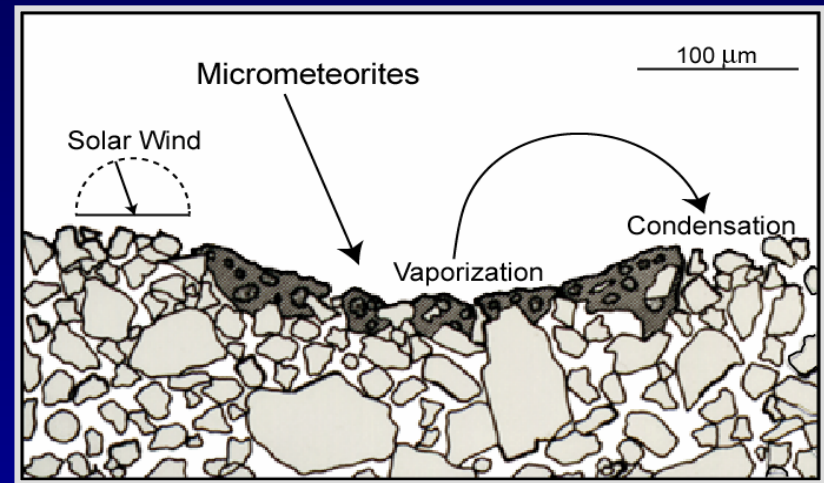
## ***Characterize and understand the regolith -- Structure and evolution of the regolith***

- Ranking: 8
- Single site:
  - This objective can be achieved best at a single, permanently inhabited site.



# Characterize and understand the regolith -- Space weathering

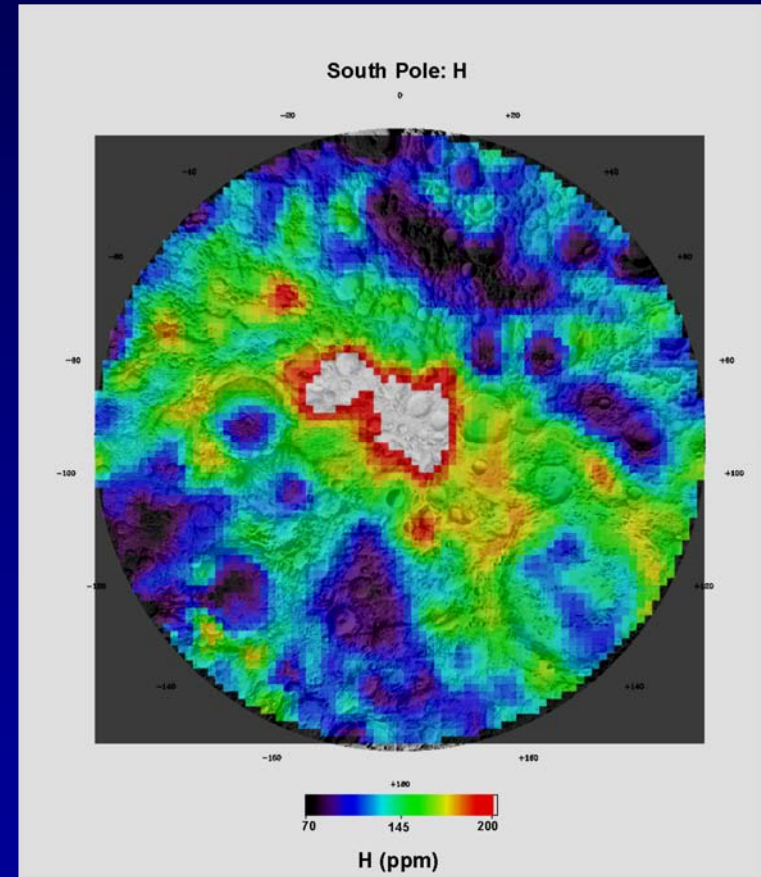
- Ranking: 6
- Single site
  - A single site is all that is required.



Space weathering processes  
(Courtesy of Larry Taylor)

# Characterize lunar volatiles -- Polar cold traps

- Ranking: 8
- Single site
  - A base is unlikely to be located within a permanently-shadowed region.
  - This is best done by robotic mission.



## ***Characterize lunar volatiles -- Composition of atmosphere (exosphere)***

- Ranking: 7
- Single site:
  - Atmospheric measurements at a single outpost site would allow study of the fate of gases added to the lunar atmosphere.

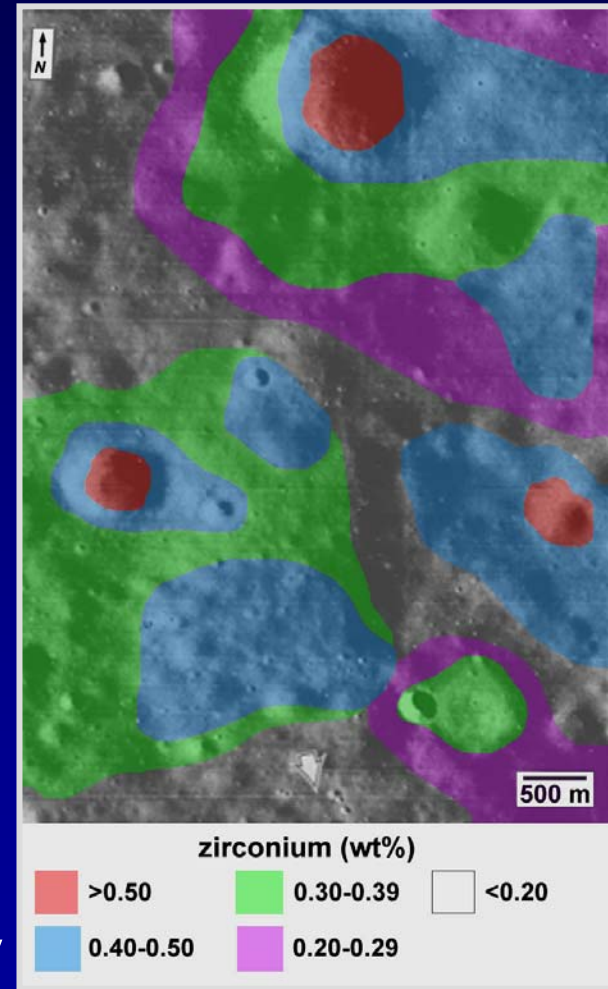


LACE (Lunar Atmosphere Composition Experiment)

# Characterize potential resources

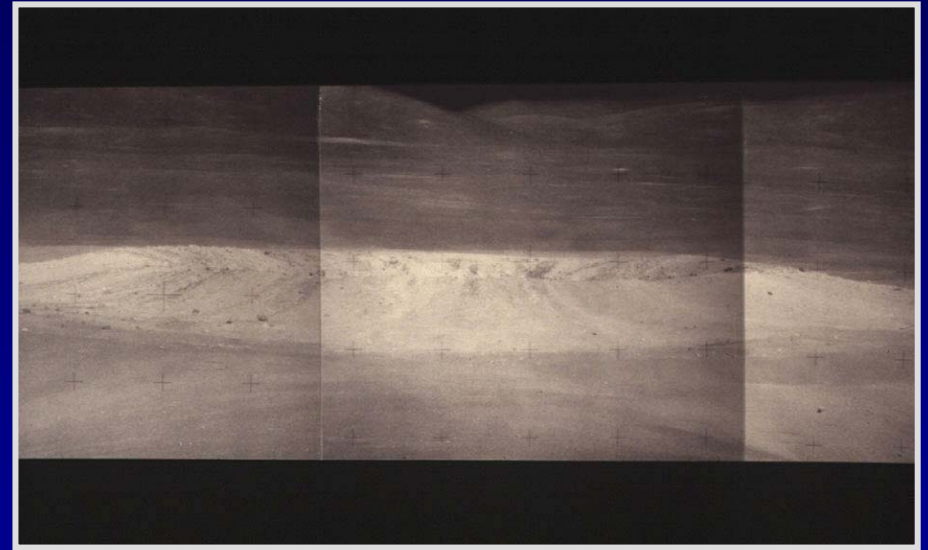
- Ranking: 7
- Single site
  - Detailed studies and sampling of the regolith can address this objective for the area around a single site
  - Global search needed

Resource Survey



# *Characterize the impact process*

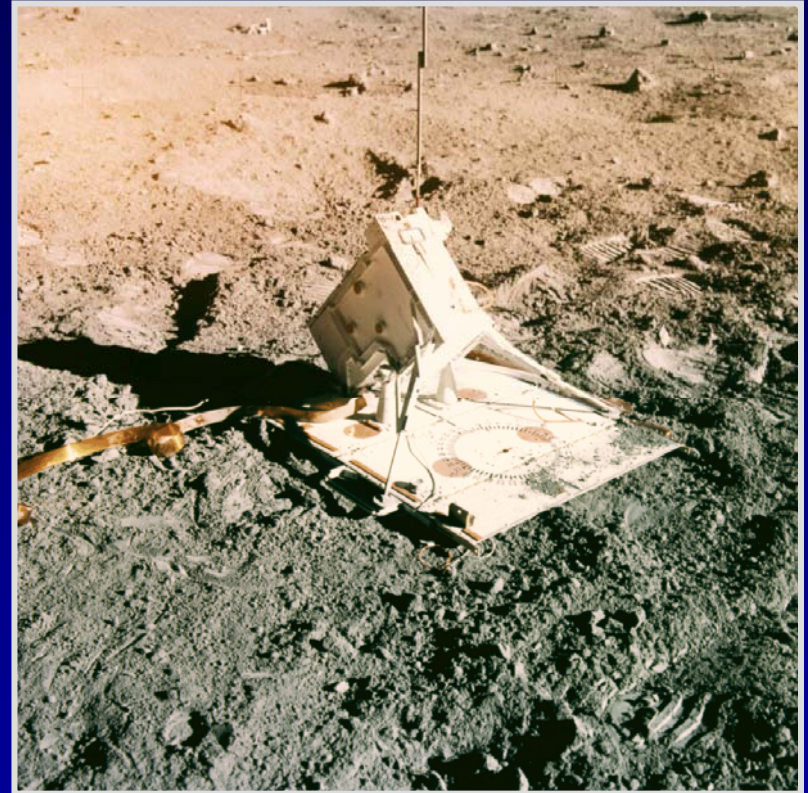
- Ranking: 8
- Single site
  - Significant progress can be made at a single site by studying one or more craters in detail.



South Ray Crater

## *Explore the uppermost subsurface structure of the Moon*

- Ranking: 6
- Single site
  - A single outpost site allows detailed studies of the local subsurface.



Apollo Active Seismic Experiment

## *Establish curation and contamination control*

- Ranking: 10
- Single site
  - Most important at a single, long-duration site.



An Earth-based curator

## *Analyze lunar samples in-situ*

- Ranking: 9
- Single site:
  - Important at a single long-duration site.



Petrographic microscope

# Setting Priorities

- Prime Directive of the VSE: settle the Moon, expand terrestrial economic sphere, and explore Mars and beyond
- Science is a major beneficiary
- But we cannot do everything we want to do
- Hence, we must establish priorities
- Base them on:
  - Intrinsic scientific merit
  - Time phasing
  - How they fit into VSE (e.g., can be done at a single site)
  - Cost